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Feasibility of Alternative Cooling Systems for Power Plants in The Northern Great Plains

By

Dr. Bruce A. Tichenor

Thermal Pollution Branch

Pacific Northwest Environmental Research Laboratory

EPA

James W. Shaw

Co-Leader

Water Quality Subgroup

NGPRP

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I. Introduction

The Northern Great Plains, particularly the states of Montana, North Dakota, and Wyoming, is a potential source of vast amounts of low sulfur coal. Recent energy shortages, strengthened with plans such as Project Independence, have increased national interest in the coal of the NGP. Since much of the coal is in thick seams relatively near the surface, ideal for surface mining, and low in sulfur, many people feel it is the ideal fuel for meeting the nation's short term energy needs.

The NGP today is relatively undeveloped in the conventional sense of the word. The present social and economic system is based primarily on agriculture. Recreational areas of national value border most of the coal country. In the western part of the coal region livestock ranching predominates and the population density is less than two people per square mile (compared to a national average of 56 people per square mile). In the eastern part of the coal region there is more dry land farming. Population in the area has not grown rapidly in the past.

Much of the area where coal is found is semi-arid to arid. Annual precipitation over the coal areas averages about 14 inches, but some areas receive considerably less. The water quality of the streams is fair to good. Water quality data, however, are not available in many areas of the NGP. When average flows prevail in streams within the area, there are surpluses in the spring runoff period to all existing uses within each tributary basin (much of the surplus has been appropriated). When snowmelt and rainfall are deficient, however, many of the streams immediately become short of water and unable to serve current needs. Water short areas have developed impoundments to store seasonal runoff. However, the Yellowstone and the Wind-Bighorn Rivers are the only rivers in the NGP that have escaped having zero flows occasionally at at least one flow recording station.

To facilitate analysis of possible impacts associated with coal development, the NGPRP developed three "scenarios" or levels of coal development that might occur. One is a base level of development, consisting largely of present commitments. One is an intermediate level and finally, one is a high level. The base level, for example, estimates coal production in the NGP at 144 million tons per year by the year 2000; corresponding estimates for the intermediate and high scenarios (by the year 2000) are 362 million tons per year and 977 millions tons per year.

Two types of coal development have been assumed. Surface mining and subsequent exportation of the coal for conversion near load centers is one alternative. The second alternative is mining and conversion of coal to other energy forms prior to exportation. Studies to date appear to indicate that physical impacts associated within mining and exportation of coal would be overshadowed by the physical and socio-economic impacts of large scale conversion facilities in the NGP. Conversion facilities will require large labor forces, water, and land and will have significant air emissions.

Water requirements, for development at the three scenario levels, have been estimated by the Water Work Group of the NGPRP. The base scenario shows a total of six power plants requiring 124,000 acre feet of water. The intermediate scenario calls for 730,000 acre feet of water annually to serve a mix of power plants and gasification plants. Water requirements for the high scenario are estimated at 1,500,000 acre feet annually, as the number of gasification plants would grow.

In the area where water needs to existing uses are not always met, particularly in dry years, the impacts of supplying large amounts of water for energy conversion must be closely assessed. In addition, careful analysis of actual water needs is required. The above water

estimates are based on a "requirement" of 19,000 acre feet of water per year for a 1000 MW power plant and of 30,000 acre feet per year for a 250 x 10^6 scf day gasification plant. Additional NGPRP studies have placed the water requirements at 12,000 acre feet/year and 9,500 acre feet/year respectively.

Some water certainly is available for additional use. When water releases from Garrison Dam are considered, water is certainly available. Of course, the location of water is not always convenient. Additional impoundments, as well as adqueducts from existing impoundments, will be necessary with an unknown impact on the existing aquatic ecosystem. The cost, both to other water users and to the environment of removing water below instream flow needs must be assessed. In some areas, ground water may be available for industrial use. While it is appropriate to evaluate all possible water sources for potential development, to better define the cost and environmental impact of its use, it is also appropriate to fully evaluate water "requirements".

The remainder of this report is a discussion of the feasibility of alternate means of cooling coal conversion plants in the NGP. While primary emphasis will be on thermal power plants, much of the discussion will also be relevant to cooling requirements of coal gasification plants. Since some cooling methods at power plants can represent over 95% of plant water requirements, it seems very appropriate to fully evaluate the feasibility of alternate methods.

II. Power Plant Water Requirements

Power plants which generate electric energy from coal require water for a variety of purposes including:

a. Boiler feedwater--heated in the the boiler to make the steam used to turn the turbine-generator.

b. Ash sluicing--used to wash away coal ash which falls from the bottom of the furnace.

c. Service water--used by plant personnel and visitors for drinking, laundary, sanitary purposes, etc.

d. Stack gas cleaning--used to "scrub" air pollutants from the stack effluent.

e. Cooling water--passed through the condenser to remove the waste heat from the turbine exhaust steam.

Items a, b, and c require small amounts of water; approximately one cfs for a 1000 megawatt power plant. Item d requires slightly more; three to five cfs. By far the largest use of water in a power plant concerns item e--cooling water.

The cooling water requirements of a power plant are determined to a great extent by the type of cooling system used by the plant. The most common cooling systems include:

a. Once-through cooling -- in this method the cooling water is pumped from an adjacent water body (i.e., river, lake or reservoir) through the condenser and discharged back to the

water body (See Figure II-1). This type of cooling system requires huge quantities of water. For example, a modern coal fired plant of 1000 megawatt capacity requires about 1000 cfs. Figure II-2 provides further information on cooling water requirements for several condenser temperature rises.

b. Closed-Cycle cooling--this method requires an off-stream cooling device to transfer the waste heat to the atmosphere (see Figure II-3). Several cooling devices are available for use:

Wet Cooling Towers are devices where the warm cooling water flows over packing material and heat loss by evaporation and convection occurs as air moves through the packing. Air movement can be induced by a chimmney effect (natural draft tower--see Figure II-4 or by a fan (mechanical draft tower--see Figure II-5). In wet towers, the cooling water is recycled back to the condenser. Water is lost by evaporation and a small amount is discharged to waste (blowdown) to prevent a buildup of undesirable dissolved materials. For a 1000 megawatt plant in the Northern Great Plains, a wet cooling tower would require an annual average of 14 to 19 cfs depending on the water treatment applied to the blowdown; under extreme summer conditions the requirement could exceed 25 cfs.

Cooling Ponds are artifical lakes which use the natural heat exchange processes of evaporation, convection, and radiation to dissipate the power plant's waste heat. Since cooling ponds also receive large amounts of energy from solar radiation, the amount of heat dissipated from a cooling pond by evaporation is generally higher than from a wet cooling tower designed to serve the same power plant. In the Northern Great Plains, the

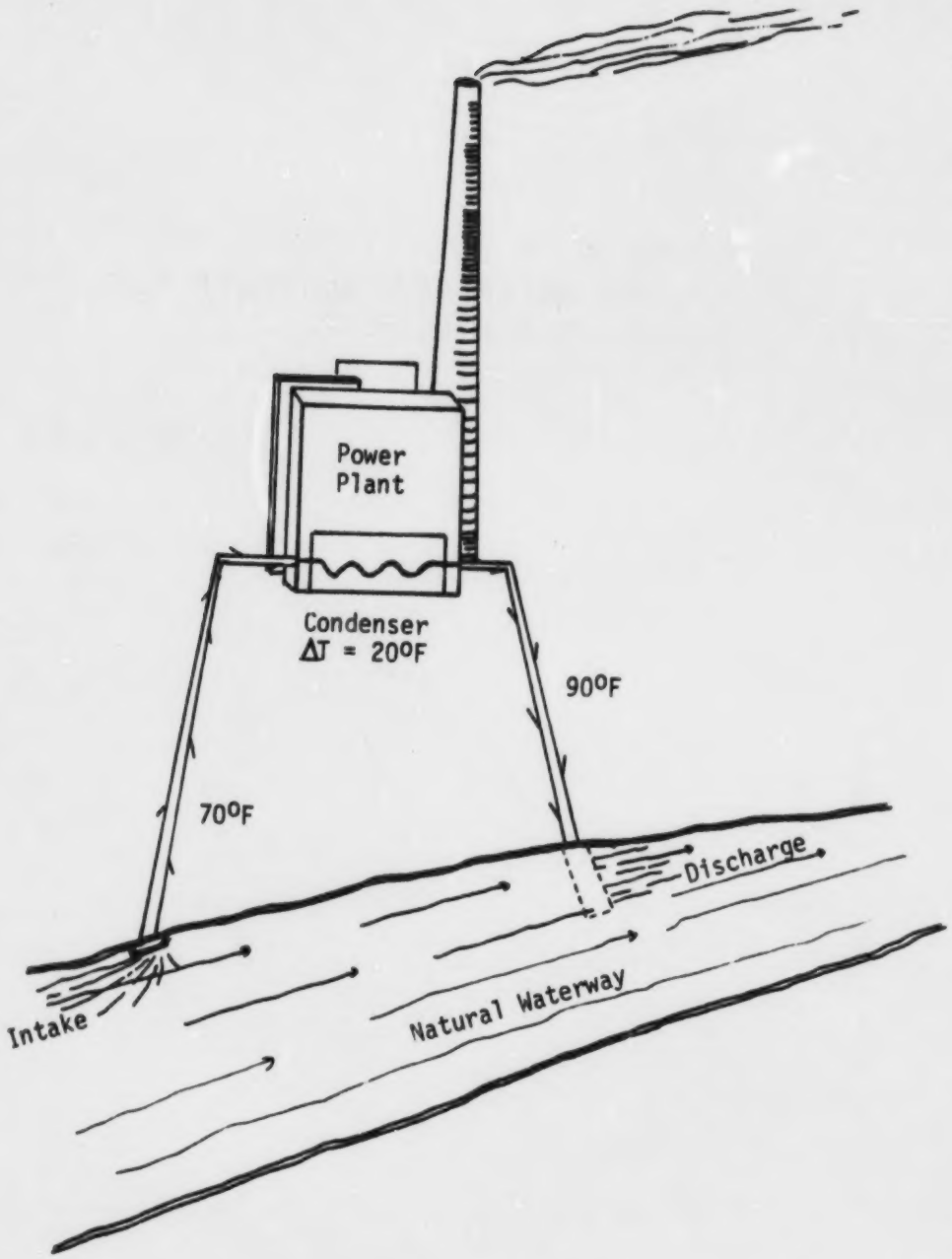
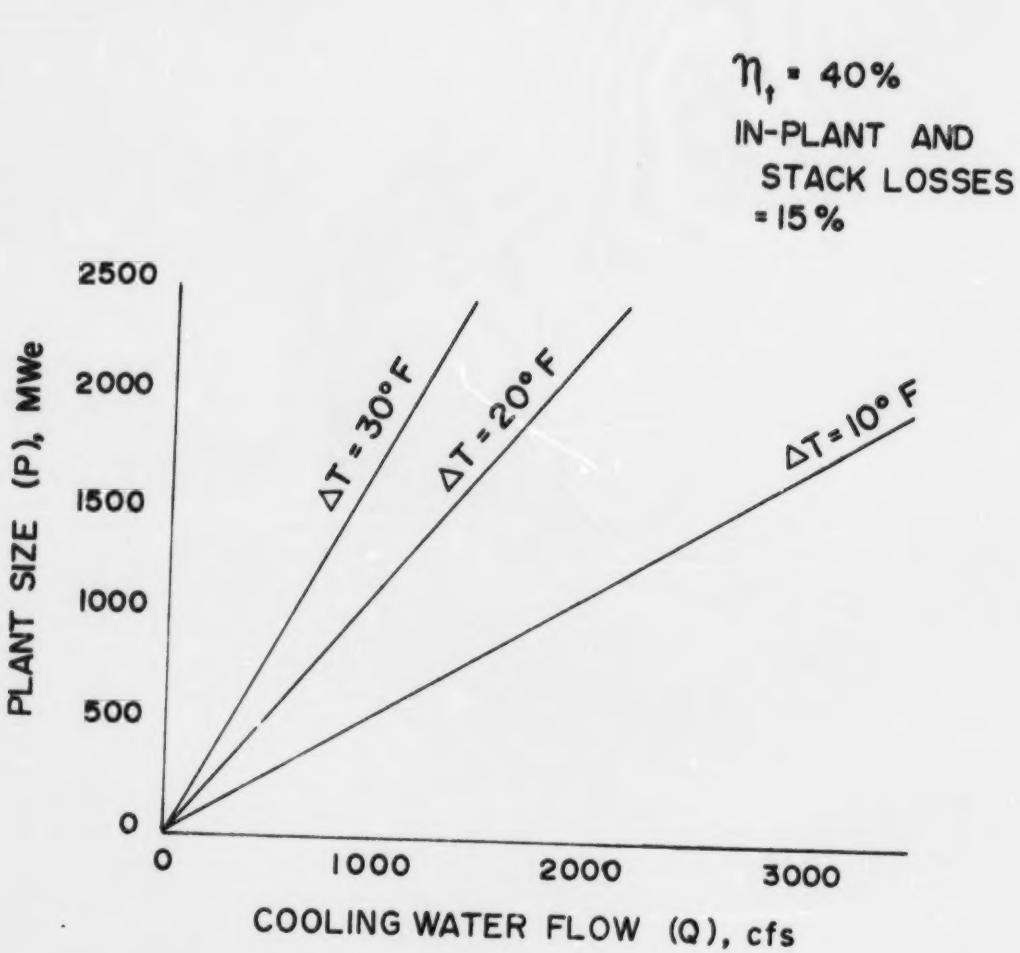


Figure II-1. Schematic of Once-through Cooling System

FIGURE II-2
COOLING WATER REQUIREMENTS FOR
FOSSIL POWER PLANTS



ΔT = CONDENSER TEMP. RISE
η_t = PLANT THERMAL EFFICIENCY

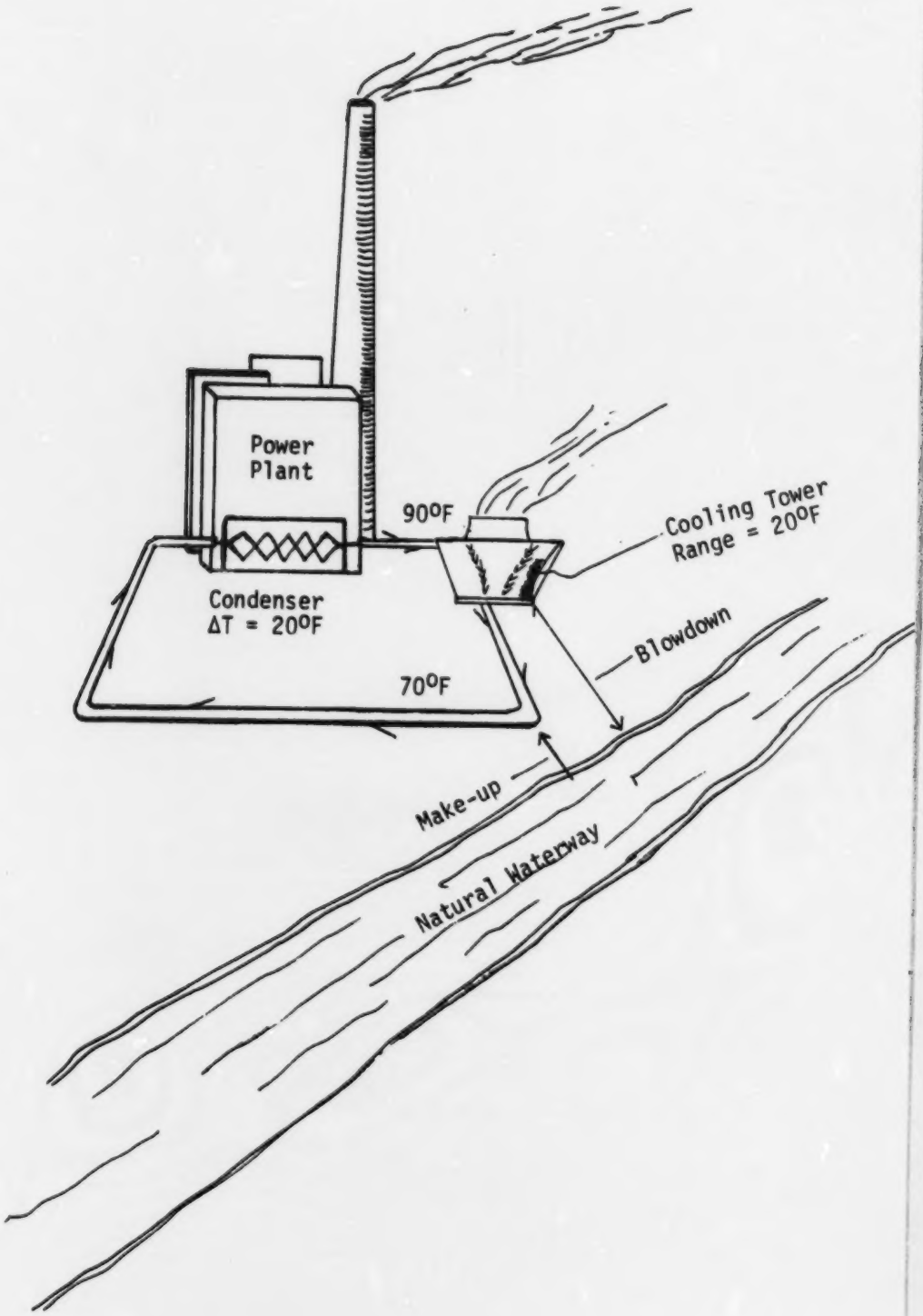


Figure II-3. Schematic of Closed-cycle Cooling System

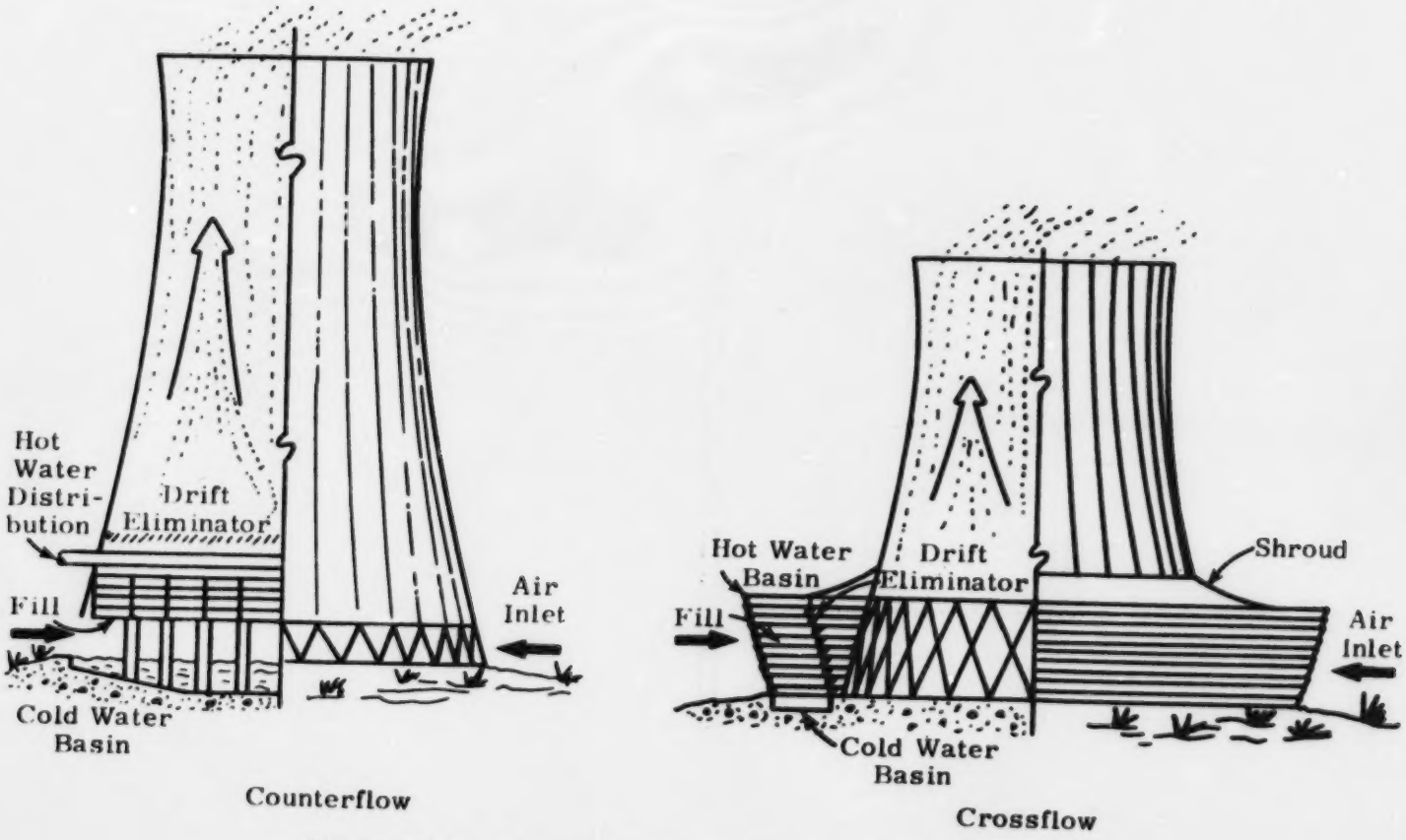


Figure II-4. Types of Natural Draft Wet Towers

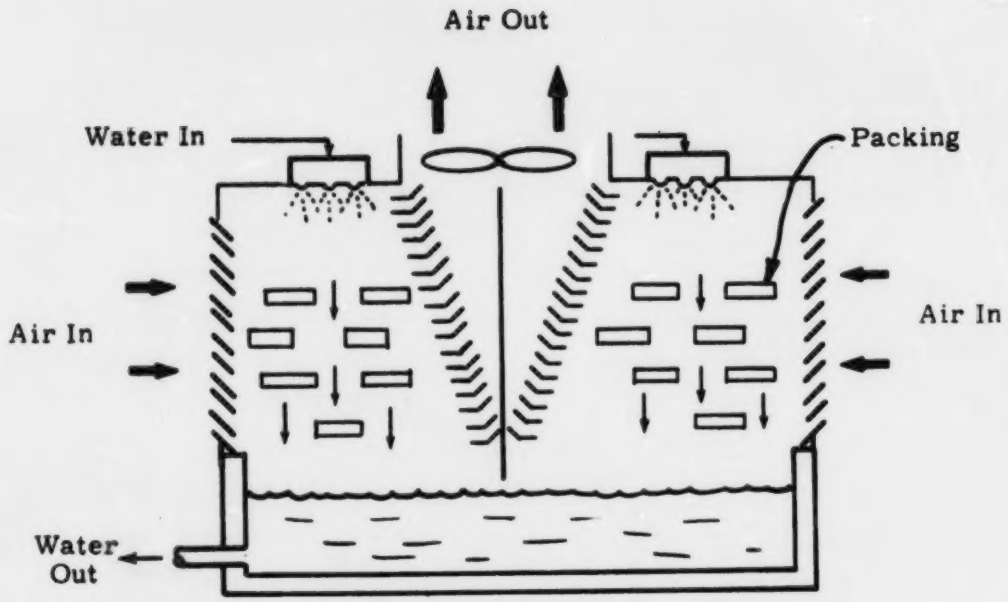


Figure II-5. Crossflow Induced Draft Tower

amount of water required for a 1000 megawatt power plant cooling pond would be about 20-25 cfs on an average annual basis; under extreme conditions the water requirement could exceed 50 cfs.

Spray Systems use fixed or floating nozzles or spinning discs to produce spray droplets. The movement of the droplets through the air provides cooling by evaporation and convection. Spray system water requirements are similar to those for wet cooling towers.

Dry cooling systems use only sensible heat transfer and are appropriate in areas of little or no water. There are two types of dry systems.

1. The direct air condenser where the turbine exhaust steam is condensed by the air and no cooling water is employed,

2. Indirect type dry systems where direct spray condensers (Heller type) are used and the cooling water and steam are mixed, with the resultant hot water going through an air heat exchanger. Thus, there is no separate cooling water system. Recent studies indicate that a standard surface condenser could be used in place of a direct spray condenser.

Dry towers, as the name implies, require no evaporation and thus no blowdown or makeup water.

Wet/dry cooling towers are constructed with both dry and evaporative heat exchangers. Such towers can be designed and

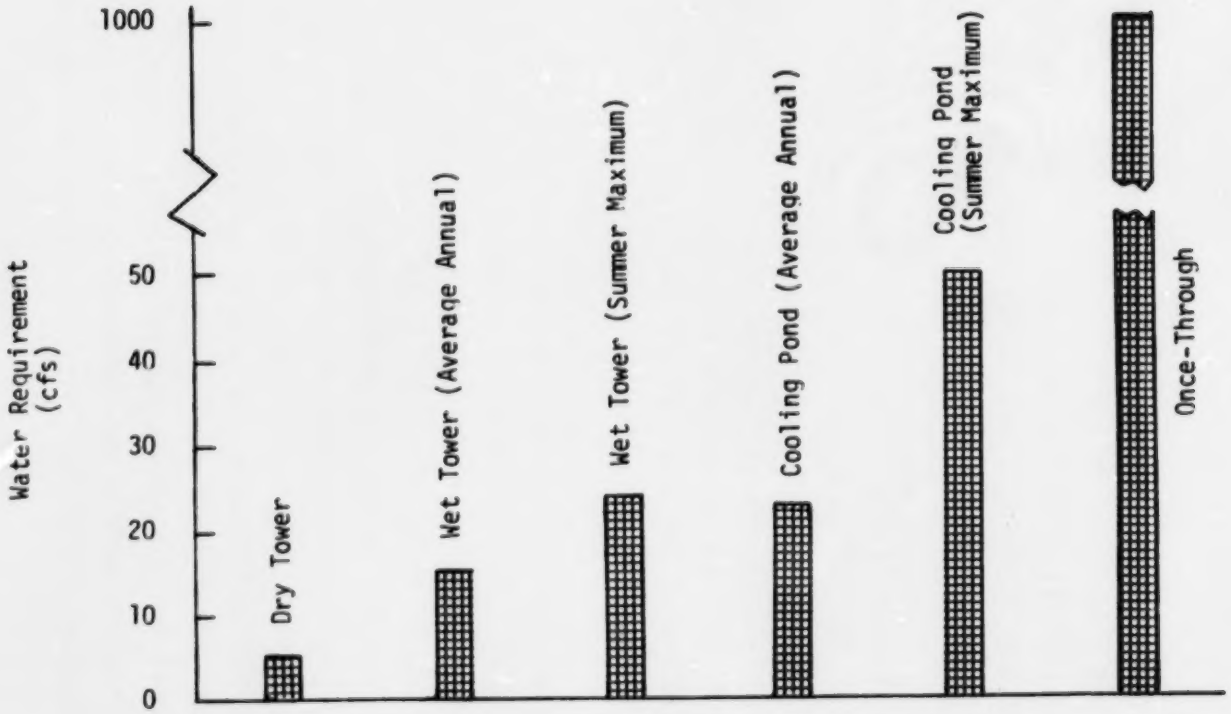
operated to reduce evaporative water loss by removing a large amount of waste heat via convection from the dry portion of the tower. Thus, water requirements of wet/dry towers fall in between wet towers and dry towers.

Figure II-6 shows the relationship between the total water requirements (including items a-e) of the various cooling systems for a 1000 megawatt coal fired power plant in the Northern Great Plains. It must be emphasized that the data contained in this figure are approximate, but they do shown the relationship between the various systems in terms of water use.

The quality of water available for cooling has a large effect on the amount of water required in a wet closed-cycle system. The higher the dissolved solids content of the water, the greater the water requirement. This is true because at a high solids content a large "blowdown" stream is required, while for extremely high quality fresh water, blowdown requirements are minimal. The water use data in Figure II-6 are based on average water quality for the Northern Great Plains study area.

A major consideration in the use of the Northern Great Plain's coal reserves is the impact on the area's water resources, both in terms of consumptive use and deterioration of quality. As is discussed above, power plant water use can range from 1000 cfs for a once-through cooling systems to 5 cfs for a dry cooling system, assuming a 1000 megawatt power plant with air pollution scrubber equipment. Excessive water requirements and the regulatory constraints of the Federal Water Pollution Control Act Amendments of 1972 make once-through cooling an unlikely alternative for much the Northern Great Plains. However, the use of parts of the Missouri for oncethrough cooling is currently under study. The relatively high water needs of cooling ponds makes wet cooling towers a more attractive alternative. From the standpoint of minimum

Figure II-6. Water Requirements* of Selected Cooling Systems for a 1000 MWe Power Plant in the Northern Great Plains



* All plants are assumed to have SO_x removal equipment and a base H_2O requirement of 5 cfs.

water use, dry towers are the most acceptable cooling system. Thus, to minimize water use, the most viable cooling alternatives for thermal power plants in the Northern Great Plains are wet cooling towers (or spray systems), dry cooling towers, and wet/dry cooling towers. The remainder of this report will discuss the engineering, environmental and economic aspects of these alternative cooling systems.

III. Operational/Engineering Considerations of Wet and Dry Cooling Tower Systems.

Operating Characteristics

Wet Cooling Towers, both mechanical and natural draft, dissipate the majority (approximately 75%) of the waste heat in the cooling water by latent heat transfer (evaporation) with the remainder lost by sensible heat transfer (conduction-convection). The wet-bulb temperature of the ambient air is the minimum temperature to which the water can be cooled. The tower is designed to cool the water to some specified temperature above the wet-bulb temperature.

The approach of the tower is defined as the difference between the cool outlet water and the wet-bulb temperature. Approaches of 15-20°F are generally used. The cooling range is the difference between the hot inlet water temperature and the cool outlet water temperature. In a closed-cycle system, the range equals the condenser temperature rise and is generally between 25 and 40°F. Thus, given information on the approach, range, and wet-bulb temperature, one can determine the inlet (hot leg) and outlet (cold leg) tower temperatures. For a given range, the lower the approach the larger and more expensive the tower, but the cooler the water and the more efficient the power plant. Thus, an optimal approach must be determined by balancing capital and operating expenditures.

In evaluating tower performance, one must differentiate between design conditions and average conditions. Design wet-bulb temperature is often designated as not to be exceeded more than a fixed percentage (say 5%) of the time during the summer months. It represents a severe condition. Average conditions will be much more moderate. For example, a particular tower may be designed for a 15°F approach, a 30°F range, and 75°F wet-bulb temperature. This would provide a 120°F tower inlet

temperature with a 90°F outlet temperature. Under more moderate weather conditions much cooler temperatures will be realized.

Dry Cooling Towers can also be designed as either natural or mechanical draft. As discussed above, all of the waste heat is discharged to the atmosphere via convective heat exchange. Thus, in theory, the minimum temperature to which the water can be cooled is the dry-bulb temperature. In actual practice, the tower is designed to cool the water to some specified temperature above the dry-bulb temperature.

The primary design variable for dry towers is the Initial Temperature Difference (ITD), which is the difference between the incoming hot water and the ambient air dry-bulb temperature. The selection of the ITD requires an evaluation of four major cost items--capital cost, auxiliary power cost, cost to the loss of capacity, and fuel cost. At large ITD's the cooling system is highly efficient and thus compact and relatively inexpensive. The auxiliary power requirements are also relatively small. On the other hand, the loss of power plant capability and the increased fuel cost due to lower power plant efficiencies caused by high cooling water temperatures are large. Thus, the capital cost and auxiliary power cost are low at high ITD's while the cost due to the loss of capacity and fuel costs are low at low ITD's. The optimal ITD for a given region is consequently dictated by the combined effects of all four cost factors. In studies conducted to evaluate dry cooling towers for thermal power plants in the Northern Great Plains, design ITD values of 60-65°F were used.

Wet/Dry Cooling Towers have received intensive study in recent years by several manufacturers. These systems, as mentioned previously are constructed with both dry and evaporative heat exchangers. The normal design provides initial cooling water passage through a dry heat exchanger with the water then falling through conventional wet cooling

tower packing. Other configurations are also possible, such as separate closed-loop cooling circuits for the wet and dry sections.

The purposes of utilizing wet/dry towers are two-fold:

1. To reduce or eliminate the visible plume emission by (a) decreasing the moisture content of the vapor discharge and (b) heating the plume to allow it to hold more water vapor before becoming saturated.

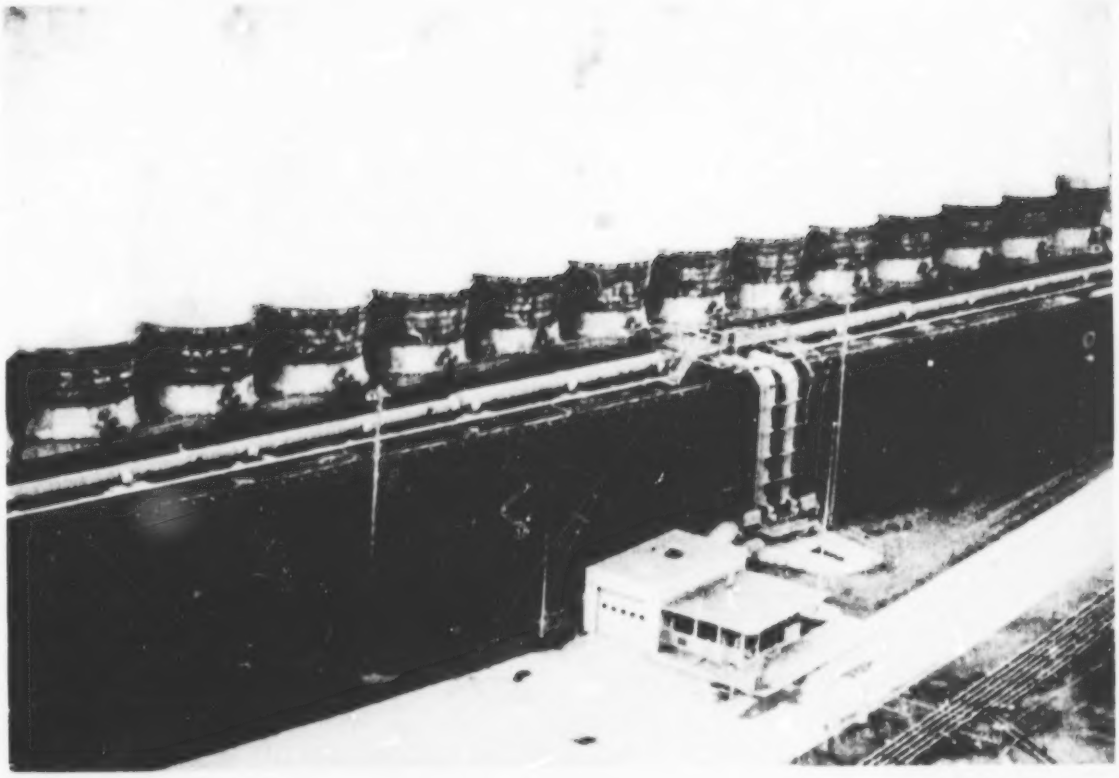
2. To reduce water consumption. The tower designer can specify what proportion of the waste heat load must be rejected by the dry section and design the tower accordingly (i.e., 50% dry, 50% wet; 30% dry, 70% wet; etc.). In general, the dry section will have a larger heat rejection capacity than the wet section when water conservation is the goal.

The operation of the wet/dry tower will depend on meteorological, hydrological, and plant-load factors. For example, during meteorological conditions conducive to fog problems, maximal use of the dry section will reduce or eliminate the visible plume. During other weather conditions, the tower may operate primarily as an evaporative cooler. Low availability of make-up water will also require maximal use of the dry section, with due consideration to the effect of high cooling water temperature on the plant's capacity and efficiency.

Availability and Reliability

Wet Cooling Towers have proven reliability and are available to meet the cooling demands of any power plant size. U.S. experience with mechanical draft towers (see Figure III-1) is extensive and several

Figure III-1



Typical Large Mechanical Draft Cooling Tower

manufacturers are available to meet any reasonable specifications. Natural draft towers (see Figure III-2) have been employed by U.S. electric utilities for over 10 years and are becoming increasingly popular for large power plants. Their reliability has proven to be very high. In the Northern Great Plains, either wet mechanical draft or natural draft towers would be a reasonable choice for a thermal power plant closed-cycle cooling system.

Dry Cooling Towers have been proven to be reliable devices for removing waste heat from power plants. Several dry cooling systems are operating and are under construction in Europe and South Africa; however, the only U.S. experience with dry cooling for power plants is at the Simpson Station in Wyodak, Wyoming. This 20 megawatt unit employs a direct air condenser (see Figure III-3). An additional 330 megawatt unit using a dry cooling system is being added to the Simpson Station.

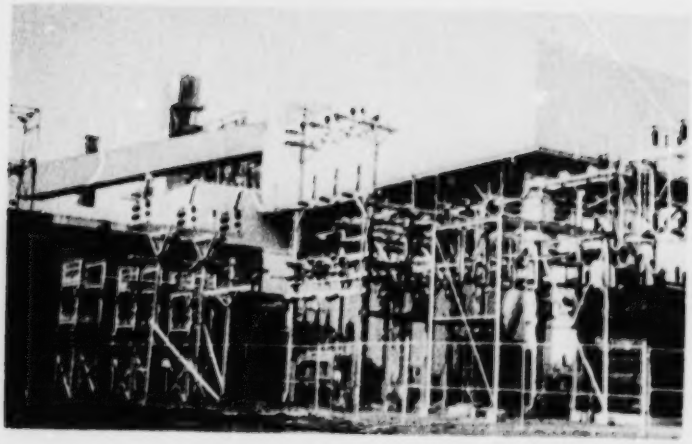
The economic and technical feasibility of dry cooling systems has been widely reported. The major obstacle to their use on large power plants in the U.S., appears to be the lack of suitable high back pressure steam turbines. A wider use of dry towers in the U.S. awaits the successful demonstration of a large prototype. The most obvious use of dry systems is at fuel-rich and water-poor locations, with the Northern Great Plains being a prime candidate.

Wet/Dry Cooling Towers have reached the stage of full-scale operation, with several U.S. manufacturers competing for the available market. As yet, no U.S. power plant operates completely on wet/dry towers, and to date only mechanical draft prototype units have been tested (see Figure III-4). The lack of experience with wet/dry towers makes it difficult to assess their reliability, although no technical impediments exist.

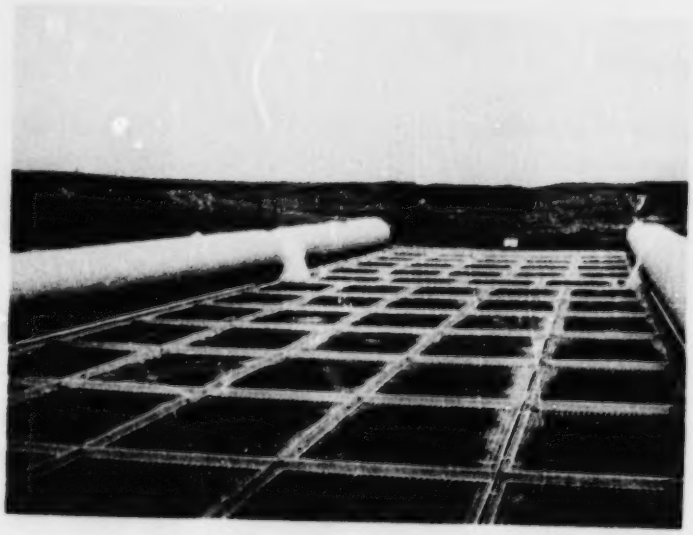
Figure III-2

Typical Natural Draft Wet Cooling Tower

Figure III-3



Side Walls Erected Around Direct-Type Air-Cooled Condensing Unit 20 MW Generating Unit



Steam Headers and Hail Screens Direct-Type Air-Cooled Condensing Unit 20 MW Generating Unit

Figure III-4

Prototype Mechanical Draft Wet-Dry
Cooling Tower

Energy Requirements

The "laws" of thermodynamics dictate that the lower the temperature of the incoming cooling water, the more efficient the power plant. Since closed-cycle cooling generally results in a higher temperature for the incoming cooling water, a decrease in power plant efficiency can be experienced resulting in increased fuel requirements for producing a constant supply of power. In addition, increased pumping power (due to the requirement to lift the water to the cooling tower packing) and the need for fan power for mechanical draft towers cause increases in power consumption. Also, on hot summer days, the power plant may experience a loss in capacity due to excessively high cooling water temperatures.

The above factors combine to provide an increase in energy requirements for a plant with closed-cycle cooling. On an average annual basis, a power plant with wet cooling towers will require less than 1% more energy than an equivalent plant (i.e., one with the same power output) with once-through cooling. A plant with dry towers will require about 3% more energy than its equivalent with once-through cooling. The additional energy requirements of wet/dry cooling will range from 1-3% depending on the proportion devoted to dry cooling.

IV. Environmental Impacts of Closed-Cycle Cooling Systems

Wet Cooling Towers

In addition to the consumption of water, wet cooling towers can have potentially adverse side effects due to vapor plumes, drift, and blowdown.

Cooling Tower Vapor Plumes have the potential for causing or increasing local fogging conditions. The key word here is potential, since in most cases, no such problems will occur. Fog is defined here as a condition where vision is obstructed.

Cooling towers do produce visible plumes; however, plumes are normally not a problem unless they reach the ground. Under normal conditions, cooling tower plumes rise due to their initial velocity and buoyancy and rarely intersect the ground before they are mixed with the ambient air and dissipated. However, under adverse climatic conditions (i.e., high humidity and low temperature), the moisture could produce a fog condition if it were trapped in the lower levels of the atmosphere, such as during a period of high atmospheric stability (i.e., an inversion). In most all cases, natural draft towers are less likely to cause fogging problems than mechanical draft towers. Mechanical draft towers may cause problems, but in most cases fogging would be on-site (i.e., within 1000-2000 ft of the tower). Also the limited vertical mixing occurring during neutral stability conditions could limit plume dispersion.

During sub-freezing weather, fogging and drift conditions may result in icing. As with fog, experience with large power plant cooling towers has not resulted in major icing problems. Methods of predicting the accumulation of ice due to cooling tower plumes are not widely

reported. In general, icing caused by plumes will be a low-density accumulation of granular ice tufts and is unlikely to cause damage due to its weight. A problem to be considered would be associated with the danger of icy roads. It should be noted that icing caused by the plume will be generally limited to vertical surfaces, and icing of horizontal roadways will be less severe.

As the water falls down through the tower packing and below, it is possible for small droplets to become entrained in the air stream moving out through the tower top. These droplets called drift have the same chemical characteristics as the cooling water in the system. The use of drift eliminators above the packing can reduce the drift loss substantially. Draft eliminators are louver-type baffles which intercept the drift particles before they can exit from the tower. State-of-the-art design can be used to obtain drift losses of 0.005% of the circulating flow rate for mechanical draft units and 0.002% for natural draft towers. In no case should the drift loss exceed 0.01% for modern, well-designed towers.

For cooling towers in the Northern Great Plains, drift should not be a problem. Except for isolated instances of electrical arcing between transmission lines, drift from freshwater cooling towers has not caused environmental problems. Separating cooling towers and switchyards by 500-1000 ft. should prevent such problems.

As discussed above, blowdown is discharged to the receiving water to prevent dissolved solids build-up in the cooling water system. For the Northern Great Plains, the original concentration of materials in the make-up water will be increased about four times prior to discharge in the blowdown. After an appropriate mixing zone, such concentration should cause no environmental problems, although discharge of blowdown in certain areas with salinity problems may be restricted. The Four-Corners area is an example of an area where salinity problems dictate no discharge of blowdown to surface waters.

A potential problem connected with cooling tower blowdown is the concentration of residual chlorine. Chlorine is added to the circulating cooling water to prevent biological fouling of heat transfer surfaces in the condenser and to inhibit biological growths on the packing in the cooling tower. The chlorine is normally added intermittently at relatively high concentrations. This periodic addition of chlorine is an effective method of control which has been widely used in the power industry. However, the toxic effects of chlorine or chlorine derivatives to aquatic organisms require minimization and close control of these constituents in effluent discharges. Fortunately, the control of residual chlorine is achievable in an economic fashion by using one or a combination of approaches:

1. Practicing split stream chlorination, i.e., treating one condenser at a time, thus providing greater dilution and lower chlorine concentrations prior to discharge.

2. Reducing the chlorine feed period.

3. Combining a discharge stream with another in-plant stream which has a high chlorine demand, such as the treated sanitary washes, ash sluice water, etc.

4. Discontinuing blowdown during periods when residual chlorine is present in the cooling tower sump.

5. Decreasing the rate of chlorine addition during feed, in proportion to the reduction of chlorine demand of recirculating water in closed-cycle systems. This method maintains a constant residual chlorine level at the condenser discharge.

6. Adding sodium sulfite, sodium bisulfite, or sulfur dioxide to blowdown to reduce chlorine at costs ranging from 0.001 to 0.014 mills/KWH.

An alternative to chlorination is mechanical cleaning of condenser tubes which, from an environmental standpoint, is the preferred method because no chemicals are employed. Balls (Amertap System) or brushes (MAN system) are passed through the condenser tubes periodically to cleanse them of biological growth. Mechanical cleaning is being used in numerous instances, particularly in new plants where it can be incorporated into the initial design. Mechanical cleaning may promote better heat transfer efficiency; disadvantages include installation and maintenance problems and potentially higher costs than chemical cleaning. Typical total costs are 0.01-0.02 mills/KWH. Also, the condenser alone is treated whereas chemical cleaning affects the entire cooling system.

Dry Cooling Towers

By the nature of their operation, dry cooling systems will not cause fogging, icing, drift, or blowdown problems. There is some controversy over what the overall environmental effects of the warm air discharge from a dry cooling tower might be. A beneficial effect may be to increase ventilation in inversion prone areas. The potential modification of local meteorology, such as triggering the formation of cumulus clouds, requires further study. Also the overall meteorological consequences of large heat releases should be assessed; however, this problem should be considered in the broad content of all large heat sources. In general, dry towers can be expected to be good environmental "neighbors." More research is needed to identify possible noise problems.

A secondary environmental consequence due to the use of dry towers is the potential increase in air pollution due to increases in stack gas

emissions. Since dry towers cause a decrease in power plant efficiency, more fuel (about 3%) will be consumed to generate the required electric power. The air pollution potential of a 3% increase in fuel use should be minimal, especially if adequate stack gas cleaning technology is employed.

Wet/Dry Cooling Towers

The fogging and icing potential of wet/dry towers is a function of design and operations. Such problems can be eliminated by using the proper proportions of dry and wet heat exchange during the winter.

Drift is caused by "mechanical" forces and is not affected by the heat exchange in a tower. Therefore, if all the water is circulated through the wet section of a wet/dry tower, one would not expect the drift rate and subsequent deposition to be much different than for a conventional wet tower.

Blowdown volume will be reduced as the amount of waste heat dissipated via the dry heat exchanger is increased. The concentration of dissolved materials in the blowdown will be the same as for a conventional wet tower. Thus the blowdown from a wet/dry tower will have a smaller impact than if a standard wet tower were used.

V. Economics of Wet and Dry Cooling Towers

A multitude of factors must be considered in assessing the cost of a wet or dry cooling tower system, including:

1. Meteorological conditions
2. Fuel costs
3. Interest rates
4. Material and labor costs
5. Plant load factor
6. Steam turbine characteristics.

In determining the cost of a power plant cooling system, both capital and operating costs are evaluated. Costs can be expressed in total cost, ($), annual cost ($/year), or production cost (mills/Kwhr, often called busbar cost). Since the cost is ultimately borne by the power consumer, translating the costs into increases in consumer costs provides the truest picture of the economic impact.

An evaluation of the costs of wet and dry cooling towers for thermal power plants in the Northern Great Plains was performed by EPA's Thermal Pollution Branch located at the Pacific Northwest Environmental Research Laboratory in Corvallis, Oregon. The results of their study are contained in a staff report by Drs. Tichenor and Shirazi, "Engineering and Economic Aspects of Wet and Dry Cooling Systems." This report discusses the analyses conducted as well as the results obtained. Table V-1 contains a summary of the assumptions and input values used.

Results of the economic analysis are summarized in Table V-2, where the difference in cost between wet and dry cooling tower systems is given for various fixed charge rates, fuel costs, and peaking season. For summer peaking, gas turbine peaking units are required to make up

lost capacity during periods of excessively high air temperatures. Since most of the power to be generated in the Northern Great Plains will be exported, summer peaking could be provided by the end user (e.g., a Chicago utility) instead of at the main power plant site (e.g., Gillette). For systems that have a peak in the winter where cool temperatures preclude the necessity to make up capacity with gas turbine peaking units, dry cooling is more economically attractive.

The results given in Table V-2 are for the Gillette site. The costs given indicate the economic penalty of selecting dry towers over wet towers. It is emphasized that these data are based on an analysis of feasibility and should not be considered hard design costs. They do reflect, however, reasonable assumptions and valid economic and engineering judgements.

The costs provided in Table V-2 show the added expense to a utility to provide dry towers. They were computed without including the cost of water for make-up to the wet towers. Table V-3 provides cost estimates similar to those in Table V-2, but with the cost of make-up water considered. Also, the increased cost to a typical residential consumer is indicated. The effect on consumer cost was calculated assuming a residential electric cost of 20 mills/Kwhr and a monthly consumption of 1000 Kwhr. It was also assumed that the consumer purchases 100% of his power from a plant with dry towers. The data in Table V-3 indicate that the average residential cost of electricity due to the use of dry towers in the Northern Great Plains ranges between $7.32 per year and a savings of $0.48 per year depending on water cost and other economic factors.

Wet/dry towers were omitted from the economic analysis because no reliable data on their costs are available. It can be assumed, however, that the cost of a wet/dry cooling tower system would fall between the costs of a dry and wet tower system.

Table V-1

Input Variables - Economic Analysis

Fuel cost - 16 and 19 ¢/10^6 BTU

Fixed Chart Rate* - 12, 15, and 18%

Average Annual Plant Capacity Factor - 70%

Meteorological Data for: Colstrip, Gillette and Stanton

Steam Turbine: Cross-compound, 3600/1800 RPM, 3500 psig, 1000/1000°F 6 flow, 38 inch last stage blades (General Electric)

*Fixed charge rate is the percent of total capital cost paid each year and includes interest, taxes, amortization, etc.

Table V-2

Cost* of Wet Versus Dry Cooling Tower Systems

Fixed Charge Rate (%)	Fuel Cost (¢/10^6BUT)	Peaking Season	Mills Kwhr	$/yr.	Total** $
12	16	summer	0.53	3,200,000	27,000,000
18	16	summer	0.74	4,500,000	25,000,000
18	19	summer	0.78	4,800,000	27,000,000
12	16	winter	0.30	1,800,000	15,000,000
18	16	winter	0.41	2,500,000	14,000,000
18	19	winter	0.46	2,800,000	16,000,000

*Cost = dry cost - wet cost for a 1000 MWe power plant with a capacity factor of 70% (water cost not included).

**Total $ = Total capital cost, including O&M costs.

Table V-3

Cost of Wet Versus Dry Cooling with Make-up Water Cost* Considered

Fixed Charge Rate (%)	Fuel Cost (¢/10^6BTU)	Peaking Season	Water Cost ($/ac-ft)	Increase in Power Cost (mills/Kwhr)	Increase in Consumer Cost (%)	Increase in Consumer Cost ($/year)
12	16	summer	150	0.36	1.8	4.32
12	16	summer	300	0.19	0.9	2.28
18	16	summer	150	0.57	2.9	6.84
18	16	summer	300	0.40	2.0	4.80
18	19	summer	150	0.61	3.1	7.32
18	19	summer	300	0.44	2.2	5.28
12	16	winter	150	0.31	0.7	1.56
12	16	winter	300	-0.04	-0.2	-0.48
18	16	winter	150	0.24	1.2	2.88
18	16	winter	300	0.07	0.3	0.84
18	19	winter	150	0.29	1.5	3.48
18	19	winter	300	0.12	0.6	1.44

*Based on average annual make-up requirements for a plant with wet towers of 17 cfs and a 5 cfs base water requirement for a plant with dry towers. This gives an average annual differential water requirement of 12 cfs.

VI. Summary

For power plants in the Northern Great Plains, closed-cycle cooling with wet, dry, or wet/dry towers are all reasonable alternatives. A comparison of the three types of towers can be made by evaluating five factors:

1. Operating experience: Wet towers rate highest followed by dry towers (a distant second at best) and, last, wet/dry towers.

2. Economic penalties: Generally wet towers are the most economical with wet/dry towers next followed by dry towers; however, this order could change depending on the make-up water cost and other cost associated with depleting stream flows.

3. Environmental impact: Dry towers have the lowest potential for environmental problems followed closely by wet/dry towers with wet towers last.

4. Water use: Dry towers consume the least water, followed by wet/dry towers, then wet towers.

5. Energy requirements: Wet towers require the smallest amount of energy, followed by wet/dry towers, with dry towers last.

Figure VI-1 provides the above information in a matrix format. The numerical ratings contained in the matrix reflect the relative merit of each tower type, with a rating of 3 being the most favorable. It is emphasized that these comparisons are given only in a general way; specific conditions at specific sites will dictate the eventual choice of the type of cooling system.

In order to enable a more precise and accurate comparison of alternative cooling system, additional studies are required to provide:

a. Complete and accurate cost data on dry tower heat exchangers.

b. Complete and accurate data on cost and performance of high back pressure steam turbines in the 500-1000 MWe size range.

c. Information on wet/dry tower cost and performance.

These information needs can be satisfied by industrial and government sponsored research.

In summary, three alternative closed-cycle cooling systems are available for use on thermal power plants in the Northern Great Plains. The selection of a specific system will depend on site related factors. Further study will enable such selections to be made with increased confidence as both better cost information is developed for hardware and operating expenses and additional costs associated with water use in arid areas are factored into analyses.

Figure VI-1

Comparison of Alternative Cooling Systems

	Wet Tower	Wet/Dry Tower	Dry Tower
Operating Experiences	3	1	2
Economic Penalties	3	2	1
Environmental Impact	1	2	3
Water Use	1	2	3
Energy Requirements	3	2	1
TOTALS	11	9	10